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Previous experiments have shown that the mammalians auditory system can be made more resistant to the traumatic effects of noise exposure by having the subject exposed to a lower level, prophylactic noise. This set of experiments was designed to see if the acquired resistance phenomenon could be adapted to protect soldiers. The specific experiments used chinchillas and focused on several questions: does the acquired resistance to noise (ARN) protect them from rifle fire and cannon fire; is it possible to develop ARN with several relatively short duration exposures; how persistent or long lasting is the ARN phenomenon.

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INTRODUCTION

The proposal, "Acquired Resistance to Impulse Noise," Log No. 94213001, is based on several years of research in our lab that showed the auditory system can be made more resistant to the damaging effects of noise by prior exposure to moderate levels of noise. For example, when chinchillas are exposed to a .5 kHz OBN @ 95 dB SPL for 6 hr a day for 10 days, the average hearing loss (.5 kHz – 8 kHz) is 50 dB; by day 5, the average loss is less than 30 dB. More importantly, if the subjects rest in quiet for 5 days and completely recover, then re-exposed to a higher level of traumatic noise they develop substantially less permanent threshold shifts than subjects without the prior prophylactic exposure. The decreased temporary threshold shift (TTS) during the 10 days has come to be known as the "conditioning" or "toughening" phenomenon. The increased resistance to PTS is known as acquired resistance to noise (ARN).

The "conditioning" and "ARN" phenomena have been reported for guinea pigs (Canlon et al., 1988), rabbits (Franklin et al., 1991) and people (Fiorino et al., 1989) so it is safe to conclude that it is a fundamental characteristic of the mammalian auditory system. Our lab has explored the limits of the phenomenon by manipulating the frequency content of the noise, the levels of the "conditioning" noise, number of days of the "conditioning" exposure and the time between the "conditioning" exposure and the traumatic exposure. (See reviews by Henderson et al., 1996 and Roberto et al., 1996). Of special interest to the Army was the finding that a .5 kHz "conditioning" exposure rendered the ear more resistant to the effects of exposure to impulse noise that simulated M-16 gunfire (Henselman et al., 1995).

The proposal "Acquired Resistance to Impulse Noise" is a rational extension of our previous research and is focused on questions that are more pertinent to the Army. Thus, one of our objectives was to learn whether the "conditioning" effect could be established with noises found in the Army. Consequently, some of the experiments included exposure to Black Hawk helicopter noise. Our original experiments involved 10 days at 6 hr./day of "conditioning" exposure. This investment in time is too

great for the phenomenon to be adopted for regular use. Thus, the proposed experiments involved a progressively shorter "conditioning" paradigm to see if it could be adapted for the military. Finally, our data with .5 kHz noise for "conditioning" and M-16 traumatic exposures showed substantially less permanent threshold shifts (PTS). The experiments in the proposal were designed to see if "conditioning" exposures protected chinchillas from simulated cannon fire as well as exposures to M-16 rifle fire.

METHODS

The overall design of the experiments was: hearing levels of chinchillas will be tested before, during, and after exposure to various experimental conditions using auditory evoked responses obtained from chronic electrodes implanted in the region of the inferior colliculus. The effects of various exposure conditions will be assessed in terms of temporary and permanent threshold shifts. At the end of the audiological test period, the animals will be sacrificed and cochlear damage will be assessed.

1. **Subjects:** Adult chinchillas will be used as subjects. The audibility curve of the chinchilla is similar to that of humans (Henderson et al., 1973) and much is already known about its susceptibility to noise. Additionally, the species is relatively immune to middle ear infections and the cochlea is readily accessed for histological analysis.

The results of noise studies on the chinchilla have contributed to the understanding of the effects of noise on this animal model, but it is also important to extrapolate the data to humans. Mills et al. (1982) compared growth of hearing loss to asymptotic threshold shift and found that orderly, but frequency-dependent relationships existed for both man and chinchilla. Although the effects of noise on the chinchilla were seen at levels 5-20 dB lower than in man, the asymptotic threshold shift growth functions of the two species were similar. No correction factor has been developed to extend quantitative PTS data from chinchillas to man, but the relation between noise parameters and PTS demonstrated in the chinchilla has provided insights on human responses to noise. Fay (1988)

compared psychophysical results from the rat, chinchilla, cat, monkey, gerbil and man. Fay argues that there is a generalized mammalian auditory system and the similarities between species are more important than the differences.

2. Surgery: Chronic recording electrode will be implanted stereotaxically in the region of the inferior colliculus and a ground electrode will be implanted just below the dura mater using techniques described by Henderson et al. (1983). The animals will be allowed to recover from surgery at least seven days before auditory evoked response testing begins.

3. Auditory evoked response recordings: Hearing status will be determined using recordings of auditory evoked responses. Auditory evoked responses in the chinchilla have been used extensively in noise research and have yielded thresholds which correlate well with behavioral auditory thresholds in the same animals (Henderson, 1983). Since the electrode primarily records activity from the inferior colliculus, the procedure allows recording of low frequency evoked potentials (500 Hz). In addition, auditory evoked responses provide objective measures which can be obtained in relatively short periods of time. Thus, the auditory evoked response is a suitable measure of hearing function in noise-exposed chinchillas, especially when testing must be performed quickly during specific post-exposure intervals.

4. Equipment and stimuli for the evoked response: Each animal will be tested in a single-walled sound-treated booth (IAC 400). The animal will be placed in a restraining yoke to ensure a constant orientation of the head within a calibrated sound field (Blakeslee et al., 1978). Tone bursts (10 msec duration, 2 msec rise/fall time) at 0.5, 1, 2, 4, 8 and 16 kHz will be presented at a rate of 20/second. The tone bursts will be generated and shaped by a signal processing board located in a personal computer. The duration and repetition rate will be controlled through the computer with a 16 bit digital to analog (D/A) converter. The sound pressure level will be controlled by an 8 bit computer-controlled attenuator before the signal is presented to an amplifier driving an acoustic suspension speaker mounted on the inside wall of the sound booth. The speaker is mounted at 90° azimuth in the horizontal plane relative to the animal's nose (i.e., directed toward the test ear).

The implanted electrodes of the animal will be connected to an amplifier with high and low pass filtering at 10 to 3,000 Hz, respectively. After amplification and filtering, the signal will be led to the input of an analog to digital (A/D) converter where it will be sampled at a rate of 100 kHz. The program has a provision for rejecting samples with large electrical artifacts. Threshold will be defined as the midpoint between a negative and positive response.

5. Evoked response test schedule: Following 7 or more days of recovery from surgery, threshold values will be obtained three times prior to exposure to the experimental condition. These three threshold measures will be averaged to calculate a pre-exposure threshold value. Post-exposure threshold measures will be obtained at 15 min. and 5 days after the last "conditioning" exposure and 15 min., 24 hr, 5 days and 10 days after the high-level exposure. Finally, three threshold measures will be obtained during the period of 25 to 33 days after the exposure to compare to the pre-exposure averages in order to determine the degree of permanent threshold shift.

6. Noise stimuli: The noise stimuli will be presented in an Acoustic Systems single wall sound booth, (6' x 6'6"). The noise will be delivered from an exponential acoustic horn (JBL) suspended from the center of the booth ceiling. The "conditioning" noise exposure will consist of an octave band of noise centered at 0.5 kHz or recorded Black Hawk helicopter noise or "M-16" rifle noise. A guassian noise signal will be generated by a random number algorithm in a D/A 16 bit signal processor (TMS-320C25) with a 50 kHz sampling rate. The noise will then be low pass filtered at 20 kHz (TDK HAF0030 active filter) to shape the spectrum of the noise. The output will be led to a driver (NAD 2200) which feeds an exponential acoustic horn (JBL 2360H). The Black Hawk noise was recorded from an actual helicopter and will be replayed at 112 dB SPL. The M-16 rifle noise will be generated by delivering a digital sample of an idealized M-16 rifle impulse to a D/A converter and then delivered to the audio system. For impulse noise exposure, the acoustic signal will be generated by a JBL 2245J compression driver coupled to a custom built 2" diameter by 8" tube.

7. <u>Calibration of the noise</u>: The spectrum and intensity of the noises will be analyzed using a noise measurement system consisting of a Type I precision sound level meter (Larson-Davis 800B) and a 1/2" (continuous noise) or 1/8" (impulse noise) condenser microphone. The sound level meter and microphone will be calibrated prior to each use with a Larson-Davis calibrator (114 dB, 250 Hz). The microphone will be mounted in the exposure chamber at a grazing incidence of 90^{o}. For continuous noise exposures, the microphone will be positioned at the geometric center of each cage at the height approximating the level of the external auditory meatus (EAM). For measurement of impulse noise levels, the microphone will be at the position of the EAM when the chinchilla is restrained. The sound level meter will be operated using the RMS function to obtain a measure of the noise sound pressure.

8. <u>Distortion Product Otoacoustic Emissions</u>: The animals will be tested unanesthetized. The subject will be held in a light restraint during the test. The probe will be positioned in the external auditory meatus so that the sound delivery tubes projects 2-3 mm from the probe tip and are about 5 mm from the ear drum. Cubic ($2f_1$-f_2) DPOAEs will be recorded from each animal before and after the noise exposure.

All DPOAE measurements will be made using a system developed in our laboratory. The measurement system includes three digital signal processors (Spectrum signal processing TMS320C25 boards) in an IBM compatible personal computer, two insert earphones (Etymotic, model ER-2), a low noise probe microphone (Etymotic ER-10 B), and custom-built attenuators and amplifiers. One of the signal processing boards is used to process the microphone output and the other two are used for signal generation. The primary tones are generated at a sampling rate of 93 kHz and output through 16 bit D/A converters. The microphone output is fed to a 16 bit A/D converter and digitized at a rate of 31 kHz. A Blackman windowing function is applied to the data stream and a partial discrete Fourier transform is computed. The frequency components corresponding to f_1, f_2 and $2f_1$-f_2 and f_n are computed. The partial discrete Fourier transform is used since it allows the spectral components to be

computed in real time for an arbitrary number of data points and the incoming data stream need not be saved. This allows spectral measurements on data samples of arbitrary length.

Spectral measurements will be made on half second intervals, requiring 15,500 data points. In order to avoid any transient effects, data collection will commence 100 ms after the primary tones are switched on. A calibration measurement will immediately precede each set of I/O function. During calibration, the primary tones will be presented at an attenuation of 20 dB. The output levels at the primary frequencies will be measured and used as reference levels for computing the required attenuation for the given signal (input) level. I/O functions will then be collected for primary tones from 0 to 90 dB SPL in 5 dB steps. The most sensitive L_1 and L_2 combination will be determined by pilot studies. Measurements will be made with the f_2 set at 1, 2, 3, 4, 5.6 and 8 kHz and the $f_2 : f_1$ ratio will be set at 1.2.

EXPERIMENTAL PROTOCOL

The original proposal was designed around three large experiments. Since the project was terminated because of lack of funds, we only had the opportunity to begin the first experiment:

Experiment I: The most efficient "conditioning" exposures. From our previous experiments, it has been learned that an OBN centered at 0.5 kHz for 6 hours a day for 10 days, works as an effective stimulus to increase the subject's resistance during future exposures to the same noise (Henderson et al., 1992) and impulse noise (Henselman et al., 1994), but not to an OBN centered at 4 kHz (Subramaniam et al., 1993b). Our data also show that almost the same amount of protection can be achieved after only two, 6 hour days of exposure (Subramaniam et al., 1993a). The following experiments are designed to determine the minimal amount of time needed for "conditioning" exposure and if the protective effect can also be established with helicopter noise.

Most Efficient "Conditioning" Schedule

"Conditioning" Exposure 0.5 kHz OBN @ 95 dB SPL or helicopter noise @ 112 dB SPL		Traumatic Exposure 100 impulses of M-16 at 150 dB
1. .5 kHZ OBN, 6 hrs x 5 days	5 days	M-16
2. UH-60 helicopter, 112 dB SPL 1.5 hr/day x 5 days (a broad band noise)	10 days	M-16

STATEMENT OF WORK

The ability of previous noise exposures to reduce an individual's susceptibility to impulse NIHL will be studied in the chinchilla animal model of NIHL. (Note, the Statement of Work pertains to a 36 month period – we had.)

I. 112 chinchillas will be exposed to one of 12 pre-exposure schedules (OBN centered at 0.5 kHz at 95 dB SPL or broad band noise at 100 dB SPL) after which they will be re-exposed to either 100 M-16 rifle or cannon fire impulse noise. TTS and PTS will be measured. The animals will be sacrificed and their cochleas analyzed.

II. 80 additional chinchillas will be exposed to a standard 10 day series of "conditioning" exposures consisting of the OBN centered at 0.5 kHz for 6 hrs/day. They will be re-exposed at either 5, 30, 60 or 90 days after the first exposure to either M-16 or cannon fire impulse noise. TTS and PTS will be measured. The animals will be sacrificed and their cochleas analyzed.

III. Twenty chinchillas will be tested for pre-exposure evoked potential thresholds, as well as DPOAEs. These measures will be repeated after Day 1 and Day 10 of the conditioning exposure (OBN centered at 0.5 kHz at 95 dB SPL for 6 hours per day for 5 days) and 5 days after the conditioning exposure. The relation between DPOAE (threshold, slope, etc.) and changes in hearing level will be correlated.

IV. Selected animals in Experiments I and II will be tested using DPOAEs before and after the 10 days of exposure.

V. Hearing will be monitored before, during and at 30 days after the last exposure.

VI. Cochlear damage will be assessed in each experimental animal.

DPOAE I/O functions: Three sets of DPOAE I/O functions (from 0 to 80 dB SPL) will be recorded prior to the noise exposure over three separate sessions (Condition 1 of Experiment I). The average of the pre-exposure measures will serve as the baseline. DPOAE I/O functions will then be recorded after the first and last days of "conditioning" exposures. Evoked potential testing will always precede DPOAE measurements and the tests will be carried out at approximately the same post-exposure time over the days of exposure. Five days after the final exposure, the animals will be tested again. In the case of animals re-exposed to the noise at a higher level, DPOAEs will also be recorded at four weeks post-exposure. At this time the DPOAE measurements will be repeated at least three times, over three separate sessions. The results of DPOAE tests made before and after the exposures will be compared to determine changes in "threshold" and in amplitudes across the primary levels. In addition, shifts in DPOAEs will be compared against corresponding shifts in EVP responses.

Predictive value of DPOAEs: Second, a noise "challenge" test, developed by Lonsbury-Martin and her associates will be used to assess whether the "conditioning" exposures strengthen the auditory system's resistance to noise as measured by DPOAE. The technique is described in Mensh et al. (1993a). Briefly, a baseline DPOAE is measured for primaries at an arbitrary level, e.g.: 50 dB SPL. With the probe still in place, the subject is given ten 10-second exposures (100 dB SPL at 1 kHz) with a 60 second quiet period between noise bursts. DPOAEs are monitored during the quiet period and the progressive decrease in DPOAE amplitude is noted over the ten quiet periods.

Mensh et al. (1993a) calculated a susceptibility index (SI), or the decrement in DPOAE amplitude over the repeated exposures. The SI has been hypothesized to reflect the subject's susceptibility to noise (Mensh et al., 1993b). In our experiments the Mensh et al. SI measurement will be done before the series of "conditioning" exposures, five days after the last "conditioning" exposure, and 30 days after the traumatic

exposure. The objective is to see if the increased resistance to NIHL is reflected as a more shallow slope in the DPOAE measures in the noise "challenge" test.

RESULTS

We have completed parts of three of the groups for the experiment designed to evaluate the most effective "conditioning" procedure:

1. Control (N=8): exposure to 100 (50 pairs), 150 dB impulse (M-16).
2. Conditioning (N=8): exposure to .5 kHz OBN, 6 hr/day x 5 days with a 5-day rest period and 100, 150 dB impulses.
3. Conditioning (N=4): exposure to helicopter noise at 112 dB, 1.5 hr/day x 10 days with a 5-day rest period and 100, 150 dB impulses.

   (a) Pre-exposure threshold: Figure 1 shows the average pre-exposure thresholds (dB SPL) for the three groups of subjects. There are no significant differences between groups and the values are in agreement with established laboratory norms.

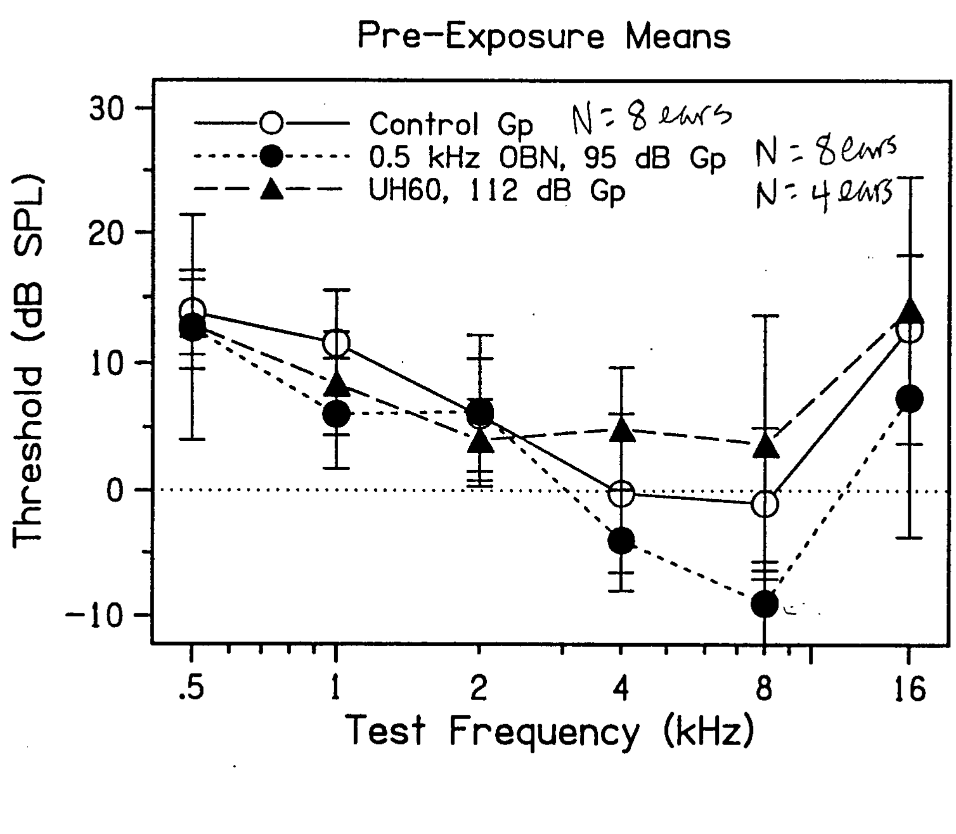

Figure 1

(b) Temporary threshold shifts during "conditioning" exposures are shown in Figure 2. The overall level of the helicopter noise is 17 dB higher than the 500 Hz OBN, but the helicopter noise has a much lower frequency energy and a much broader spectrum. Consequently, the helicopter noise produces about the same level of TTS at lower frequencies (.5 and 1 kHz), but substantially more at upper frequencies. By 10 days, the amount of low-frequency TTS caused by the helicopter noise, was 20 dB less than Day 1.

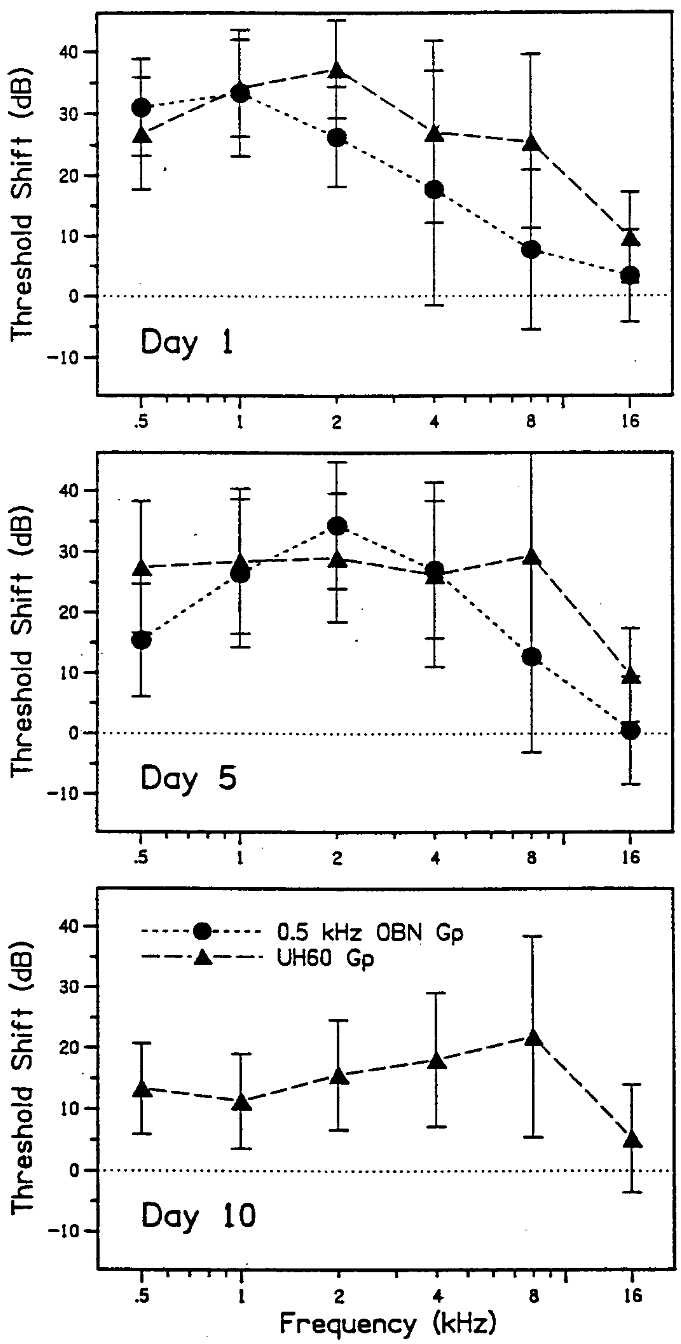

Figure 2

(c) Residual hearing loss 5 days after "conditioning" exposure is shown in Figure 3. Both of the "conditioning" exposures produced a minor threshold shift (7 – 20 dB) that was still measurable 5 days after the "conditioning" exposure. One cannot be certain if this is a permanent change in sensitivity or a persistent TTS that will require another 5 to 10 days to recover.

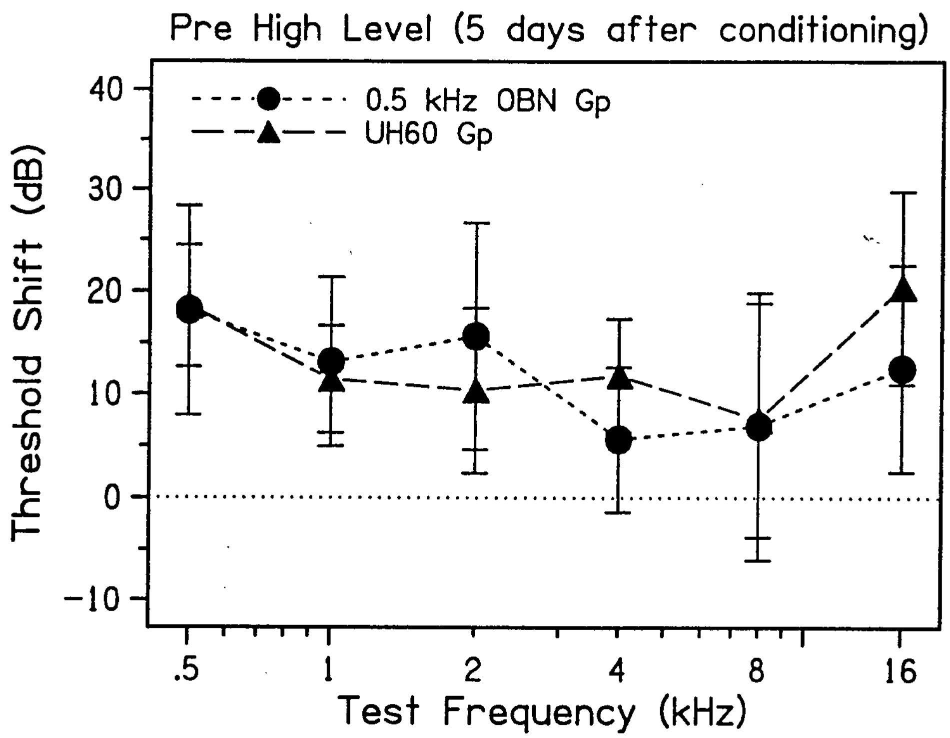

Figure 3

(d) Permanent threshold shifts after "M-16" exposure are shown in Figure 4. The acoustic energy in the M-16 like impulse is centered at approximately 2 kHz. The control, on average, has 10 to 18 dB more PTS at the higher frequencies and approximately the same PTS at the lower frequencies. It should be noted, however, that the large variability is evident by standard deviations. The protection seen in the two "conditioning" groups is even more impressive when considering that both groups had approximately 13 dB TTS when exposed to the "M-16" impulses.

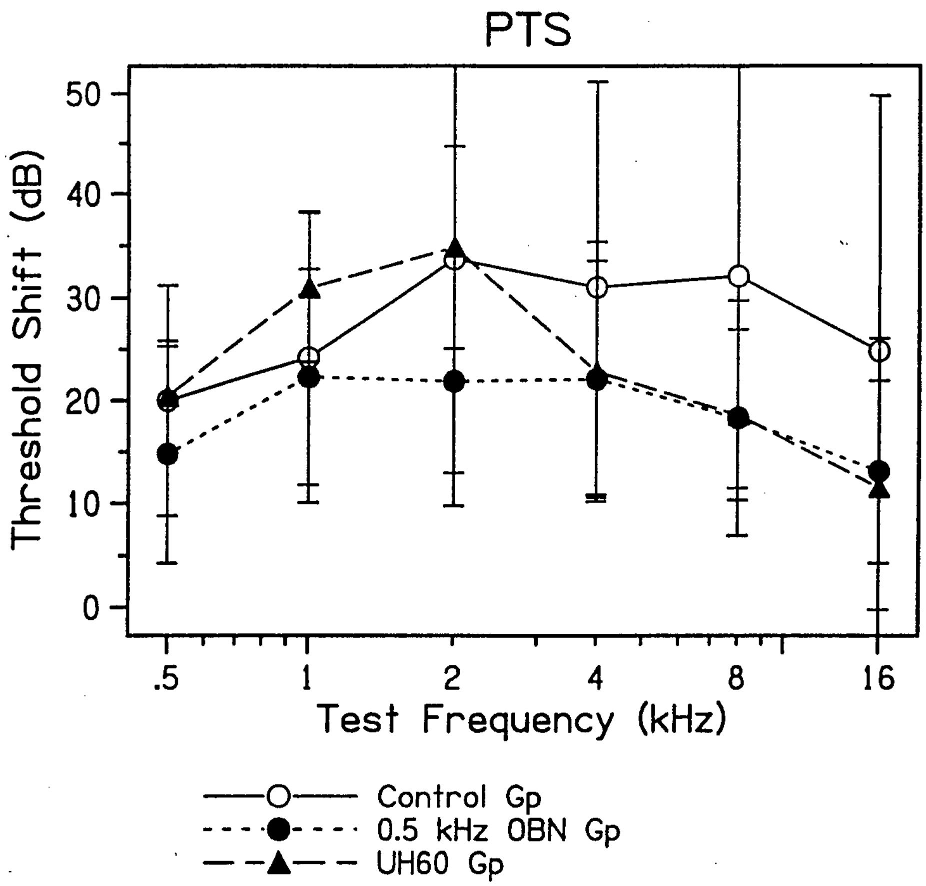

Figure 4

DISCUSSION

The termination of the grant after the first six months severely limited the progress we have made on the proposed experiments. However, the data we have acquired confirms our initial hypothesis that the auditory system could be made more resistant to impulse noise such as “M-16” gunfire.

The “conditioning” exposures used for the two experimental groups, the .5 kHz OBN @ 95 dB SPL for 6 hrs/day x 10 days and the recorded Black Hawk helicopter noise at 112 dB caused a level of TTS that had not fully recovered over the 5 days of quiet following the auditory exposure. Nevertheless, both groups developed significantly less PTS than a control group after exposure to the 155 dB “M-16” impulses. These results are so important that it would be worthwhile to repeat the exposures with less total acoustic energy during the “conditioning” exposures, i.e., either lower intensity levels or shorter duration exposure so that the subjects completely recover by five days after the “conditioning” exposure.

The optimal "conditioning" exposure, i.e., shortest duration and maximum protection was the goal of the first part of the proposal.

One of the secondary goals of the project was to identify subjects that were either especially sensitive, or conversely resistant to noise. Our operating hypothesis was that the strength of the distortion product otoacoustic (DPOAE) would be an indicator of susceptibility. Unfortunately, because of the truncated period of the project, the number of animals completed does not allow for meaningful statistical analysis on the susceptibility question.

CONCLUSION

The chinchilla auditory system can be made more resistant to the damaging effects of "M-16" like impulses by prior exposure to a .5 kHz OBN @ 95 dB SPL for 6 hrs/day x 5 days or recorded Black Hawk helicopter noise at 112 dB for 1.5 hrs/day x 10 days. Both of these exposures involve less time for "conditioning" than our original experiments demonstrating the ARN phenomenon. Thus, the results are promising with regard to the development of practical "conditioning" techniques for application to the Army.

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REFERENCES

Blakeslee, E.A., Hynson, K., Hamernik, R.P., Henderson, D. (1978): Asymptotoic threshold shift in chinchillas exposed to impulse noise. J. Acoust. Soc. Am. 63, 876-882.

Byrne, C., Henderson, D., Saunders, S., Powers, N. and Farzi, F. (1988) Interaction of noise and whole body vibration. In Manninen, O. (Ed.) Recent Advances in Research on the Combined Effects of Environmental Factors. Tempere, Finland: ISCES, 239-254.

Canlon, B., Borg, E. and Flock, A. (1988) Protection against noise trauma by pre-exposure to low level acoustic stimulus. Hear. Res., 34: 197-200.

Fay, R.R. (1988) Comparative psychoacoustics. Hear. Res., 34: 295-306.

Fiorino, F., Gratton, M., Subbanna, M., Bianchi, L., Henderson, D. (1989) Physiological mechanism underlying the progressive resistance to noise induced hearing loss. Valsalva LXV (Suppl.1) 36-41.

Franklin, D.J., Lonsbury-Martin, B.L., Stagner, B.B. and Martin, G.K. (1991) Altered susceptibility of $2f_1 - f_2$ acoustic-distortion products to the effects of repeated noise exposures in rabbits. Hear. Res., 53: 185-208.

Henderson, D., Subramaniam, M., Spongr, V., Attanasio, G. (1996): Biological Mechanisms of the "Toughening" Phenomenon. In: Auditory System Plasticity and Regeneration. (Eds: Salvi, R.J., Henderson, D., Fiorino, F., Colletti, V.) Thieme Medical Publishers, New York, 143-154.

Henderson, D., Campo, P., Subramaniam, M. and Fiorino, F. (1992) Development of resistance to noise. In Dancer, A., Henderson, D., Salvi, R.J. and Hamernik, R.P. Noise Induced Hearing Loss, St. Louis, Mosby-Year Book, 476-488.

Henderson, D., Hamernik, R.P., Sitler, R.W. and Salvi, R.J. (1983) The evoked response audibility curve of the chinchilla. J. Acoust. Soc. Am., 54: 1099.

Henselman, LW, Henderson, D, Shadoan, J, Subramaniam, M, Saunders,,S, Ohlin, D (1995) Effects of noise exposure, race, and years of service on hearing in U.S. Army soldiers. Ear and Hearing 16(4), 382-391.

Henselman, L.W., Henderson, D., Subramaniam, M. and Sallustio, V. (1994) The effect of "conditioning" on hearing loss from impulse noise. Hear. Res. (In Press).

Hetu, R., Lalonde, M. and Getty, L. (1987) Psychosocial disadvantages associated with occupational hearing loss as experienced in the family. Audiology, 26: 141-152.

Mensh, B.D., Patterson, M.C., Whitehead, M.L., Lonsbury-Martin, B.L. and Martin, G.K. (1993a) Distortion-product emissions in rabbit: I. Altered susceptibility to repeated pure-tone exposures. Hear. Res., 70: 50-64.

Mensh, B.D., Lonsbury-Martin, B.L. and Martin, G.K. (1993b) Distortion-product emissions in rabbit: prediction of chronic-noise effects by brief pure-tone exposures. Hear. Res., 70: 65-72.

Mills, J.H. (1982) Effects of noise on auditory sensitivity, psychoacoustic tuning curves and suppression. In: R.P. Hamernik, D. Henderson and R.J. Salvi, Eds. New Perspectives on Noise-Induced Hearing Loss. New York: Raven Press, 249-264.

Roberto, M; Hamernik, RP; Ahroon, WA; Case, CJ (1996): The Effects of Primed and Interrupted Impact Noise Exposures on Hearing Loss in the Chinchilla. In: Auditory System Plasticity and Regeneration. (Eds: Salvi, R.J., Henderson, D., Fiorino, F., Colletti, V.) Thieme Medical Publishers, New York, 165-180.

Subramaniam, M., Henderson, D. and Spongr, V.P. (1993a) Protection from noise induced hearing loss: Is prolonged "conditioning" necessary? Hear. Res., 65: 234-239.

Subramaniam, M., Henderson, D. Campo, P. and Spongr, V.P. (1993b) The effect of low frequency "conditioning" on hearing loss from high frequency noise. J. Acoust. Soc. Am., 93: 952-956.